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Federal Communications Commission
Office of Secretary

Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, DC 20554

In the Matter of	)	
	)	
Advanced Television Systems and Their Impact Upon the Existing Television Broadcast Service	))))	MM Docket No. 87-268

FCC 96-207 – FIFTH FURTHER NOTICE OF PROPOSED RULE MAKING

COMMENTS OF

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I file these comments on July 10 1996, in the FCC's Fifth Further Notice of Proposed Rule Making in the Matter of Advanced Television Systems, MM Docket No. 87-268. These comments are mine only and do not necessarily represent others at my organization.

Submitted by:

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Progressive versus Interlace Scanning
Vertical Resolution, Flickering, and Aliasing

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Introduction

Progressive scanning for video has long been preferred because of its freedom from interlacing artifacts. Progressive gives quiet images free of the fatiguing interlace flickering found in detailed regions with finely patterned horizontal or diagonal edges. This is why it is used almost exclusively in high resolution computer displays. Despite this, interlacing has been used because it can have more scan lines per complete image within a given screen refresh rate and bandwidth.

What has not been well appreciated is that in practice interlaced cameras seldomly deliver images with the full vertical resolution implied by the number of scan lines, chiefly because of the flickering problem. There are inherent design trade-offs between vertical resolution, flickering, and aliasing in an interlaced camera. They can either have a lot of flickering and aliasing, or have low vertical resolution. In either case, the perceived quality of this resolution is lower than expected from the line count.

Progressive cameras are free of this compromise, simply because they read out the entire image at once, They can be easily built to produce images with maximal vertical resolution with minimal aliasing, and absolutely no flickering. Thus, contrary to traditional thinking, progressive cameras can deliver images that are equal or better than typical interlaced images in terms of resolution and quality -- within the same bandwidth and refresh rates.

Image Sampling with Solid-State Imagers:

Solid-state electronic image sensors, in particular Charge-Coupled Devices (CCD), are greatly preferred over tubes for their superior image quality. They are highly sensitive, reliable, and free of many of the problems with tube systems. These devices consist of rectangular (or preferable square) grids of photo-sensitive elements. Each picture element, or pixel, samples the light intensity at that location for each image acquired. Because these pixels are arranged with regular spacing they are susceptible to sampling errors, known as aliasing or Moire effects. Aliasing occurs when the image contains finely spaced light-dark-light patterns such as picket fences or venetian blinds, where the spacing of one pair of light-dark lines is finer than the spacing of a pair of pixels in that direction. When this happens in an image, the fence or blinds start showing large bands of light (Moire) that are not related to the original scene, and that move around unnaturally as the camera moves.

Avoiding aliasing requires that the finely detailed regions be filtered, or blurred, so that the sensor grid does not detect them. Inevitably, this blurring also reduces the sharpness of the rest of the image. Many techniques have been explored over the years for retaining the most sharpness in the image while minimizing aliasing.

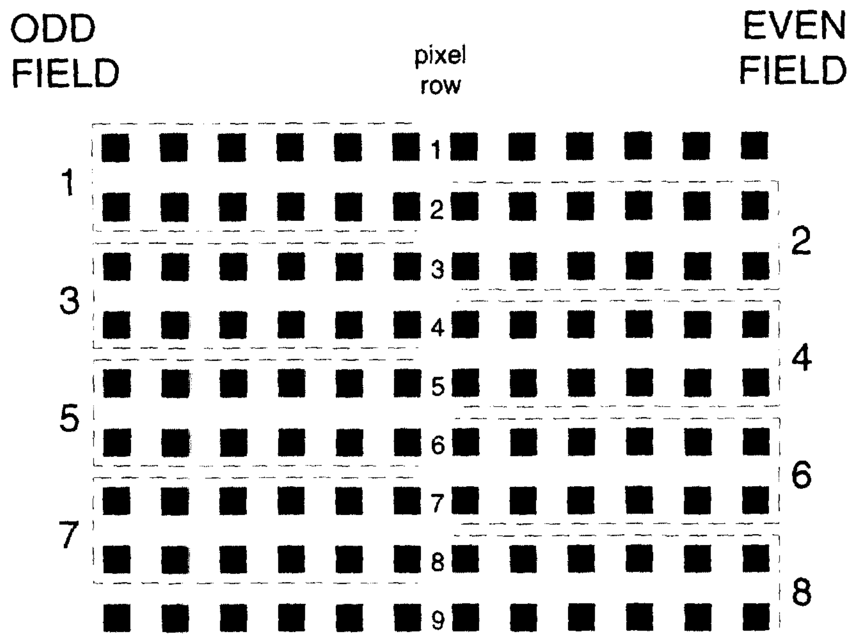
The best and simplest optical low-pass is a birefringent crystal that shifts half of the light a given amount in one direction, while letting the other half through unchanged. This acts as a precisely controllable amount of blur, that in combination with the sampling aperture of the CCD pixel selectively filters out the spatial frequencies that cause aliasing while leaving the rest of the image sharp. These optical low-pass filters are used in most CCD video cameras sold today.

The design of interlaced and progressive cameras are similar in the horizontal direction. A optical low-pass filter with image offset matching the pixel's width is placed in front of CCD aligned so the shift is in the horizontal direction. Thus neither type of camera will have much trouble with picket fences.

In the vertical direction a progressive camera will use the same trick. A second optical low-pass filter matching the pixel's height is placed in front of the other filter, curing the problem with venetian blinds. Such a filter is seldomly used in interlace cameras, because of their special problems.

Vertical Sampling in an Interlaced Camera

The situation is much trickier for the interlaced camera. The image is acquired in two passes (fields), usually with two separate exposures. In the first field only the odd lines are to be scanned out, while in the second the even rows are scanned out. There are several different ways of implementing such a system, each of which having a different set of problems.



Field Mode operation of interlaced CCD camera, showing how pixel rows are combined to form odd and even lines. This results in lower vertical resolution.

The simplest way would be to just read out the signal from the pixels in the odd rows, while ignoring that from the even rows. During the second field, you would read the even ones and skip the odd ones. This is sometimes call "Enhanced Vertical System" (EVS). For proper image sampling, this should be used with a vertical optical low-pass filter to avoid aliasing. If it is, the static vertical resolution of the camera would begin to approach that of a progressive system with the same number of scan lines.

However, this approach has two serious problems. Image scenes with horizontal stripes, such as venetian blinds, will at some magnification have the light bars falling on the even rows and the dark ones on the odd rows. When the scene is displayed in an interlaced manner, that region will blink from black to white at the frame rate (every other field) and be very objectionable. This same flickering will also be evident along horizontal and diagonal edges, including the edges of text and graphics. The second problem with EVS mode is that half the signal is being discarded, cutting light sensitivity in half. For these reasons this method is almost never used in practice.

The most common method for interlaced scanning is to add the signal from the image rows in pairs, shifting the manner in which the pairs are combined to form the even and odd fields (often called "Field" mode). For the odd field, pixel rows 1 & 2 are combined to form line 1, 3 & 4 to form line 3, etc. In the even field, pixel rows 2 & 3 form line 2, 4 & 5 form line 4, and so on. This has two advantages -- it serves to vertically blur the image like an optical low-pass filter would have, and it preserves all the signal for full sensitivity. Unfortunately, the resulting image now has a vertical resolution that is only slightly better that one-half what it had in the EVS mode, or about 60 % of that of a progressive camera with the same number of lines.

Some camera manufactures use a hybrid approach that involves combining a small amount of the alternate pixel row with the row nominally being read out ("Super Enhanced Vertical System"). This is a compromise between the previous two alternatives, yielding some flickering and some loss in sensitivity for some improvement in resolution.

Because interlaced cameras usually rely on combining rows to reduce flickering, they cannot afford to add vertical optical low-pass filters which would further compromise resolution. Unfortunately, this means that higher vertical spatial frequencies may Moire as well as flicker, leading to all sorts of unnatural and electronic-looking effects.

Discussion:

As a result of the overlapping between the interlaced scans, interlaced cameras do not achieve in practice the static vertical resolution implied by their scan line counts. In fact, a progressively scanned camera with 2/3's the number of scan lines of the interlaced camera will produce an image with similar or better vertical resolution, and the progressive images will completely free of flicker. Also, the progressive camera can have significantly less aliasing at the same time.

The situation for dynamic resolution is much more clear-cut in the favor of progressive. Since the entire image is sampled at the same time, the full resolution is available in each frame. Interlaced frames, on the other hand, consist of two half-resolution images taken at different times. At no time is a full "field" resolution image available -- trying to combine two fields to generate a frame only results in large loss in resolution both horizontally and vertically even with computationaly intensive motion-estimation.

Interlace has been traditionally touted as being a more efficient way of coding images than progressive scanning. For a given number of scan lines in the entire frame, interlacing does result in less large-area flickering in CRT displays because the screen is repainted twice as often. However, as a result of the vertical filtering to suppress small-detail flickering, the information transmitted is more redundant and less efficient of bandwidth or data rate. This low efficiency (60%) nearly counters the gain due to interlacing.

With two-thirds the vertical pixel count and a similar reduction in the horizontal direction to keep the resolution even and natural-looking, it is possible to make a progressive camera with a frame rate matching the field rate of an interlaced camera. The static image from such a camera is equal or better in perceived quality than the interlaced camera in informal testing, and the dynamic resolution is far better since each of the frames has full resolution.

Conclusion:

Interlaced scanning involves a fundamental design trade-off in the camera between vertical resolution, flickering, and aliasing. Practical solutions to this problem used in commercial cameras result in actual resolution far less than that implied by the number of scan lines. Because the opto-electrical design is so much simpler for progressively scanned cameras, high resolution and much better perceived quality can be obtained with fewer scan lines. This improvement in quality and usable resolution per pixel counters the nominally higher data rate needed for progressive scanning, resulting in better overall quality for progressive scanning within the same bandwidth used for interlacing.